A Work Project, presented as part of the requirements for the Award of a Master Degree in Finance from the NOVA – School of Business and Economics

Estimating and forecasting international yield curves: a no-arbitrage VAR with macroeconomic and latent variables

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A Project carried out on the Master in Finance Program, under the supervision of:

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DATE:

28/12/2017

Author's Note

This is an individual report associated with a work project carried out by a group of five students, under the supervision of Professor Martjin Boons and the aid of BlackRock. This project stands as a thesis for the award of a Master's Degree in Finance at Nova School of Business and Economics.

Abstract

The focus of this paper is to replicate and extend a model for the prediction of interest rate affine term structure models. We propose an extension of one of the most recent models in the field to some G10 countries. Our purpose is to find how well this model fares at forecasting in different markets and if its implementation in investment strategies is viable. This model uses measures of real activity and inflation as macroeconomic variables together with unobservable variables. This Work Project had the objective of delivering its results to BlackRock to build an innovative and successful investment strategy.

Keywords: *Interest Rate term structures, Affine Term Structure Models, Macroeconomic variables, Latent Variables, Minimum Chi-square Estimation*

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Theoretical and Methodological Context

The present paper strives to replicate and extend to other countries a model for the prediction of affine interest rates term structures (IRTS). This framework is based on the crucial work developed by Hamilton and Wu (2012) and also Ang and Piazzesi (2003), which elaborate on the already existing literature of Gaussian Affine Term Structure models developed by Vasicek (1977), Duffie and Kan (1996), Dai and Singleton (2002) and Dufee (2002).

The paper by Ang and Piazzesi (AP) (2003) (JME) contributed with the main framework for the model estimated, which includes both observable and unobservable factors (and their lags) when estimating affine interest rate term structure forecasting model. The observable factors include "Inflation" and "Real Activity", obtained through a principal component analysis. The unobservable factors are three, representing the conventional "Level", "Slope" and "Curvature". Data for yields is collected for five different maturities and three of these yields will, by definition of the model, be observed without error. Nevertheless, seeing that we are dealing with this particular class of Gaussian affine term structure models, we will be able to get predictions for a continuous IRTS. AP's solution, obtained through a Maximum Likelihood Estimation (MLE) was, however, proven to be unidentified in more recent researches.

Regarding the Hamilton and Wu paper (HW) (2012) (JE), we focus on the contribution they made to the estimation of a model with the same basic framework as AP but using Minimum Chi-square estimation instead of MLE, which prior to this had never been applied in predicting IRTSs. This change improved the estimation of the "Macro Finance Model with 12 Lags", presented in AP.

In conclusion, the main intent is to expand the existing literature to other countries belonging to the G10 and do an analysis of the quality of the model's forecasts using RMSE (Root Mean Squared Error). Moreover, it was also a goal to make this an automatized predicting process that uses the most recent and reliable data available. The preferred code language was MatLab.

Diagnostic of a Certain Challenge

First step of the work project was collecting the data in order to both replicate the previous studies of AP and HW using data for the U.S. from 1952 to 2000 and extend the model to other developed countries. Our purpose is to find how well this model fares at forecasting in different markets and considering different estimation period (pre and post crisis). Moreover, we want to investigate whether or not the implementation of the model in investment strategies is possible. The Affine Term Structure Model (ATSM) presented by AP and HW is given by a Gaussian term structure model with time-varying *risk premium* which depends on both observable (macro-economic) and unobservable (latent) variables. The main idea behind this framework is that models that use macro factors have greater forecasting power than models that use only latent factors: bond yields are determined by three correlated latent factors together with inflation and real activity measures.

In order to proceed with the replication, we started with the collection and analysis of data. For the estimation of the model, we are going to collect monthly data for both macro variables and yields. The sample of data we used for the replication is the same as the one adopted by AP, except for the bond yields for which we have a different starting month:

- Macro variables: the data ranges from January 1952 to December 2000.

  Macro variables consist of two groups: inflation and real activity measures. Inflation measures are based on the CPI (Consumer Price Index), PPI (Producer Price Index) of finished goods and PCOM (spot market Commodities Prices). Real activity measures are based on the HELP (index of Help Wanted Advertising in Newspapers), EMPLOY (Employment index), IP (Industrial Production index) and UE (Unemployment rate).[1]

[1] Inflation measures at time t are calculated by applying $\log(P_T/P_{T-12})$ where P_t is the inflation index. The growth rate in employment and industrial production are calculated by applying $\log(I_t/I_{t-12})$ where I_t is the employment or industrial production index.

The macro data have been separated in two groups in order to reduce the dimensionality of the system to two final macro factors ("Inflation" and "Real Activity") throughout a Principal Component Analysis.

- ZCB Yields: For the 1, 3, 12, 36 and 60-months yields, which are from the Fama CRSP files, the sample period we have used is from December 1952 (instead of June 1952 as it is in AP) to December 2000. The 1, 12 and 60-months yields, which represents the short, middle and long ends of the yield curve, are measured without error. The 3 and 36-months yields are measured with error. The main reason is that yields of near maturity are extremely correlated.

However, the main purpose of our work project is the comparison of results between the United States and other G10 countries. For the data collection we used Bloomberg terminal and Thomson Reuters Eikon.

At the very beginning we wanted to build a panel of ten countries. However, when we started to collect the macro data we went through the first problem related with data collection: for most of the countries there was not availability of data with regard to inflation and real activity measures either because the series were not available or the starting dates were too recent and we would end up with series which were too short for the estimation of the model. We decided then to look for the "best proxies" in order to overcome the problem of "not availability" of the series. However, even by using proxies for the inflation and real activity measures that were not available, the problem related with the starting date was still persistent for some of them. As a result, we had to exclude some countries from our panel. Finally, we chose Canada, Germany, Japan and the United Kingdom. For those, we collected the most recent up-to-date macro and yield data. Beside these countries, we are also going to apply the model to the United States, by extending the sample period to the most recent available data.

For all countries, the code is built to take in the most recent up-to-date data. Indeed, we had to adjust the data set with regard to both macro and yield data:

- Macro variables: for some countries, we had to replace some inflation and real activity measures with the corresponding best proxies. For the United Kingdom we used RPI (Retail Price Index) as a proxy for CPI, that way we were able to increase considerably the length of the series since the CPI was only introduced in the UK at the end of the 1990s. For Germany, Japan and UK we used CCI (Commodity Channel Index), adjusted with the exchange rate for each currency, as a proxy for PCOM. The CCI-index measures price movements of 22 commodities and it exists since 1957 and before it was called CRB (Commodity Research Bureau) index. For Canada we used BCPI (Bank of Canada Commodity Price Index) as a proxy for PCOM. With regard to real activity measures, HELP was the only series for which we had to find the corresponding proxy for all the countries. For US, the HELP had been discontinued in September 2009. In order to make the series updatable, we combined it with "Job Vacancies" used as a proxy from September 2009 until today. For Canada we were not able to find a proxy for HELP, for this reason it was not included in the "Real Activity" factor. For all the other countries we used "Job Vacancies" as a proxy.
- ZCB yields: we used IRS (Interest Rate Swap) as a proxy for the ZCB yields. The main reason is that the IRS is a good approximation of the risk-free rate, the same as government ZCB. For the 1 and 3 months yields we could not find the IRS and, in these cases, we used: *Canada Banker Acceptance* for Canada and *Ice Libor* for all other countries.

Once the data collection has been completed, we went through another problem also related with data: for each country's data set we had to adjust the length of the series because there needs to be a match in the availability of months for yields and macro data.

- Macro variables: for each country, we had to cut each series according to the least data available, so that historically all series start at the same point. This process has been automated in the MatLab code. Moreover, when dealing with updatable data and with the purpose of using the most recent values, we applied AR(1) for the missing data of the updatable series when different series' newly released values are available in different days of the month.
- ZCB yields: for all countries, the model always uses five different maturities for the yields. The 1, 12 and 60-months yields are measured without error while the 3 and 36-months yields are observed with error. We automatized the MatLab code so that it cuts the data by the lowest series' length. The reason is that the length of the yield data series needs to match the length of the macro data for the optimization.

Main Conclusions and Learnings

Doing a group project as a master thesis was not a straightforward decision: first of all, a group of five members may have a lot of advantages related with the splitting and allocation of task but, at the same time, working together with four other people means there needs to find a "group-schedule" which takes into account five different timetables. Moreover, since working together in a group sometime leads to discordances, I was afraid this might have obstructed the developing of the project.

After more than three months working together as a group, I can successfully affirm that taking part in this work project was the best way to conclude my "academic journey" for two main reasons. First of all, I have enjoyed the challenge. The topic we had to develop was complicated in terms of both theory and MatLab coding. We had to start from the scratch in order to understand the theoretical framework behind the papers (AP and HW) that we had to replicate, adjust the code in order to both extend the model to other G10 countries and find how well it fares at forecasting in different markets and according with different estimation period.

At the beginning we did not know how to carry out such a complex work project. However, by always operating as a group, we were able to end up with an overall positive result. Even more important in my opinion, doing a consulting project as a master thesis made me able to take part in a practical experience which is the most effective way of learning by working together with my group-mates and helping each other to overcome any problem we went through during the development of the project.

Last but not least, we were able to use the time we had in an efficient way by splitting the tasks according with our skills. We decided to allocate two members on the data collection and analysis and three members on the MatLab coding. This division was not drastic, in the sense that we were always collaborating considering the needs we went across. Together with another group member, I had to take care of the collection, analysis and treatment of data and the set-up of the final power point. As I have previously mentioned, we thought that exploiting each one's skills would have led to better result in terms of both output and to "use of time". This represents the main reason why I propose myself to be allocated in that task.

To enjoy the challenge, to work always together as a group, to learn from each other, to help each other when it was necessary, to use the time we had in an efficient way, to carry out a complicated project, to overcome any problem by collaborating and to not get discouraged by difficulties represents my personal takeaways from this experience which I am going to bring in my incoming professional life.